

A Discourse concerning the Air's Gravity, observ'd in the Baroscope, occasioned by that of Dr. Garden; presented to the Phil. Soc. of Oxford, by the reverend Dr. Wallis, President of that Society. April, 14, 1685.

THE Discourse of Dr *Garden* (read at our last meeting,) concerning the different state of the *Air*, in respect of its different gravity, hath in it a great deal of very ingenious speculation. And what I then said to it, upon the first reading of it, and what I am now saying again to the same purpose, is not to contradict it, or detract from it, but to add to it; as a notion which I have long since considered, and judge it capable of further improvement.

The notion of the *Air's* weight and spring, hath been so well settled, by innumerable Experiments of this present *Age*; that hardly any considering Person doth now doubt of it.

And it hath chased away from before it, the notion of *Fuga vacui*, formerly received; by shewing us an efficient cause, of those effects, for which before we could onely pretend to a Final cause.

The first occasion (that we know of,) of introducing it, was, from *Galileo's* discovery, that water, by Pumping, was not to be rais'd higher then about three or four and thirty foot (or not much more,) of our *English* measure,

Which was a certain argument, that the cause of those effects (commonly ascribed to *Fuga Vacui*,) was but of a finite strength: whereas, if natures shunning a Vacuity had been the true cause, it was to have operated without stint.

Where upon this *Lyncean Philosopher* (as he was called,) did, out of his great sagacity, guess happily at the counter-

ter-balance of the *Air's* weight, as the true cause. And that therefore *Air*, which was before thought to be a light body, was but comparatively so, and had indeed a positive gravity, though less than that of other bodies which we are conversant with.

This notion, was happily pursued by (a Successor of *Galileo*,) *Torricellio*; who did rationally argue; that, if the *Air's* counterpois was sufficient to raise and sustain water at that height, and but to that height; then must it be a just counterpois to a lighter Liquor at a greater height, but, to a heavier Liquor, at a lesser height. And making an essay thereof in *Quick-Silver*, found it to succeed accordingly: and, in a just proportion to the respective gravities of those fluids.

And he hath, by this means, made the experiment (commonly called the *Torricellian* experiment,) much more manageable with *Quick-Silver* (in Vessels of about 29 Inches, *English* measure,) then before it was, with water, in much taller Vessels.

In pursuance of this notion, we find, by several sorts of Baroscopes (or weight-wisers,) not only that the *Air* hath gravity, but that it hath a different gravity, at different times and places; according as its counterpois is able to sustain *Quick-Silver* at different heights: sometimes a little lower then 28 Inches, sometimes a little higher then 30 Inches, and at other times at some middle height between these, here with us. Which different weight of the *Air*, or *Atmosphere*, may reasonably be supposed, partly to proceed from, and partly (as *Dr. Garden* well intimates,) to give occasion of difference in the weather and winds.

The particulars of his discourse (having not the Paper with me, and having but heard it once read,) I may possibly mis-remember. But, as to the main drift of it, (being a notion not wholly new to me,) I think I do not mistake.

That there is, in our *Air*, a body more subtle then are the Fumes and Vapours mingled with it, in our lower region, and which with it do make up that heterogeneous mixture which we commonly call *Air*; I think to be very certain. But whether that subtle body, be (as Dr. *Garden* seems to suppose,) much heavier, then our common *Air*; I much doubt. And do rather think it is not; not having hitherto observed any cogent experiment, either to prove it heavy, or elastick. But it may, for ought I know, be void as well of weight as spring: and, what we find of either, in our common *Air*, may be attributed to the other mixtures with it.

I know that this notion (of the greater weight of that subtler matter,) hath, by some, been made use of, to solve that (surprising,) experiment of *Quick-Silver* (well cleansed of *Air*,) being sustained in a Tube inverted (after the manner of the *Torricellian* experiment,) at a much greater height then the usual standard (of 28, 29, or 30, Inches, even to the height of 40, 50, 60, or even 70, Inches; being steadily managed, and with great care. But I confess I am not satisfied with that reason: and think that it may better be accounted for otherwise, or else we are yet to seek for the true cause of it.

But we have no need of this particular notion, in the present discourse, and therefore need not be here solicitous about it: and shall therefore proceed without it.

The *Air* being, as hath been said, of a different gravity, in different times and places, (arising I suppose, from the different kinds and quantities of the Fumes and Vapours and other particles which are ingredients in it, and the different force of the Suns heat acting thereupon, increasing or allaying the spring thereof, and otherwise,) we are therefore to consider of the *Air* as a fluid who's parts are in some places heavier, and others lighter. And therefore much of a like nature as if they were different fluids, of different specifick gravities (as the word is now
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a-days,) or (as it was wont to be called, and, I think better,) Intensive gravity, one from the other: (as, when we say, an Ounce of Lead, is intensively, though not Extensively, heavier then a Pound of Cork.)

Now when several fluids, or several parts of a fluid, are thus of different weights; they will (from the general nature of heavy fluids,) when undisturbed, change places with one another, till the heavier becomes lowest and the lighter highest.

And this, not onely as to the minuter parts; as is observed in Chymical precipitations, or the sinking of Sand in water, or its smaller earthy particles which subside in a muddy sediment, and the like of other Liquors when at rest, and the atoms (as they were wont to be called,) flying in the *Air* when disturbed, but subsiding in the form of dust when at rest. All which according as they be smaller do (*Ceteris Paribus*,) subside more slowly (as dust slower then a clod of Earth, and Filings of *Gold* slower then a lump of it, and thin Plates of Lead layd horizontally, then either a round Bullet of the same weight, or those Plates in a contrary position set edgewise,) and ought by statick principles (as is easily demonstrable,) so to do. But, much more, as to larger parcels. As when Oyl, Wine, Water, Beer, or other the like Liquors, are put together in the same Vessel; as will be observable to the Ey, especially when their colours are considerably different.

Thus, if a Bucket of Water, be hastily taken out of a Pond, or a large Vessel full of it, the vacant place will be presently supplied with *Air* (as the nimbler fluid,) & then with Water flowing (by a declivity,) from the higher parts, and (because heavier,) thrusting out the *Air* (which had prepossessed the place,) till it come to a due Equipois.

And the same (from a like reason,) must happen, if some parts of the same Liquor, do accidentally acquire (by expansion or otherwise,) a greater degree of lightness then the other parts; those lightned parts ascending,
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the heavier subside. As when Water, Beer, or other thin fluids, be gradually heated by a fire underneath; the lower parts, being first warmed, ascending to the top, while the colder and heavier subside; whence we find, in such cases that Bubbles do arise, and that at the top is warmer then that at the bottom. But in case what is warmed, be of a thicker consistence, so as that the parts cannot readily shift places, that at the bottom will be hotter; and in case it be heated by fire over it, there will (I suppose,) be not such bubbling (or not so much of it,) that at the top being first heated.

From such consideration as this, Dr. *Garden* doth well observe, that some parts of the *Air* being thus (by rarefaction, or increasing the spring thereof, or otherwise,) become lighter then others; these heavier parts, rushing into the places of those lighter, may cause a wind as from such parts; (in like manner as, on a like occasion, a Tyde or Current would arise in water;) and other accidents of a like nature. And contrarywise, on a contrary occasion.

And this I take to be very true, (though such accidents happening very variously and uncertainly, will cause such confusion of motions, and disturbance of each other, that it will be hard to reduce them to a regular adjustment.)

But I add thereunto, that the Earths diurnal motion, compounded with its annual, (if we admit that hypothesis, as most do now a-days,) the one in some parts accelerating, in others retarding the other; and its difference in different times of the year, (by reason of the obliquity of the *Zodiack* to the *Equinoctial*,) and in different times of the month (because of the Moons different position, which is an Appendance to the Earths motion, and doth thereby differently affect it,) and according to the different place of the Earth and Moon, as to the Aphelion or Perihelion of the one, and the Apogæum or Perigæum

perigæum of the other: seem to me to be of much greater consideration, not only as to the Ebbing and Flowing of the *Sea*, (which I take to depend principally thereon, but to be variously modified also by the various positions of the continent on which it beats,) but as to the Winds also: especially the breezes and Trade-Winds; which at certain times of the day, or of the year, or of the month, are observed to blow constantly (or most frequently,) from such or such a Coast.

And I am not sure, that the body of Earth and Water (or *Terraqueous Globe*,) is exactly spherical (allowing onely for the small inequalities of Hills and Dales, which in a body of that greatness, are inconsiderable,) but may have somewhat of an oblong spheroid, having a longer *Axis* from Pole to Pole, then at the Equator. And though this cannot be much; because of the Earths shadow in the Moons Eclipse appearing circular, and the descent of heavy bodys being always (as to sense,) in a perpendicular to the *Horizon*: yet, if it be but little, this (with the compound motions before mentioned,) will give the *Air* a considerable disturbance.

To which I may add also, that we are not sure, that the *Seas* and continents (which are of very different comparative weights, Earth being heavier then Water,) are so adequately adjusted the one to the other, as that its center of gravity (by which a plain passing divides it into parts æquiponderant,) is the same with its center of Magnitude (by which it is divided into parts equally great,) which if it happen to be otherwise, will (with the rest,) make the confusions of the *Air*'s motions yet greater. From the comparative weight or lightness of the *Air* at different times, he deduceth also the rising or falling of Vapours in it. As if, when such Fumes or Vapours, or other the like matters, are lighter then the *Air*, they ought (according to the exact rules of Hydrostaticks,) to ascend therein; but, when heavier then so, to fall

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down. And this certainly (*cæteris Paribus*,) is to be admitted also.

Onely I add thereto; that these statick principles do cheiffly take place, when things are otherwise at rest and quiet. But when they are in commotion, it is many times much otherwise. And, in such cases, we must, beside the respective gravity, take into consideration, the force, impulse, or impetus, that is superadded to the respective gravity of the parts or matter.

Thus, if a Bottle be shaken, the sediment at the bottom, (though heavier, and for which cause it did before subside,) will be mingled with the supernatant (finer and lighter,) Liquor. And, if a room be swept, it will (as we use to speak,) make a dust: that is, the small Earthy particles of dust, will rise and mingle with the *Air*: not because they be lighter then it, (for we see that, at leisure, they will subside again,) but because, by a force upon them, they be put into motion. So in a Jetty of Water (in artificial Water-Works,) the water is thrown up into the *Air* to a great height; not because it so becomes lighter then the *Air*, but because of the force impressed. (To say nothing of a Bullet, shot upward into the *Air*.) And Bottled Ale, when opened, flies many times upward to a great height; and sometimes blows up the Cork, to release it self from confinement. And, in the late Fire of *London*, not Papers only, but other things of greater weight, were mounted into the *Air*, and there carried aloft for many miles, and so taken up at more then Twenty miles distance.

And this I take to be the cause of Fumes, Vapours, and other like matters (most of them,) which ascend in the *Air*, not because lighter then it, but because impelled upward out of the bowels of the Earth, or from the superficial parts of it, either by some subterranean heats or other ferments that put them into motion, and force them upward; where they remain suspended in the *Air*, so long

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as that force continues, or the force of others sent after them on the like errand (which rather impells them farther, then gives them leave to fall,) till either such force abate, or the great weight of so many things suspended, doth overpower, not only the *Air's* weight, but the strength of that, that impelled them.

And that there are such Fumes and other like matter projected upwards, from the Bowels of the Earth, and some of them with great violence, is undeniable, not onely from Earthquakes, and other eruptions (with great noises,) as well of Vapours, as of Burning *Mountains*; but even Poisonous Steams (and others,) in *Mines*, and Bubbling springs (where Bubbles of *Air* are seen to make their passage through the Water,) and other perspirations of *Air* or Vapour through crannies or small passages of the Earth, discoverable by Steams (whereof some will take fire at the light of a Candle,) or by the moving of Leaves and other light things laid on the mouths of such private passages, and by many other means. And to such causes I do principally attribute the Origine of Winds, and the ascent of most other things, which, from this lower World, mount into the *Air*. And, without this, the comparative gravity of the *Air* and them, would give us but a lame account of them.

There is yet another notion suggested, which is also very considerable as to this affair: which is, the weakening or strengthening the spring of the *Air*. That Water hath (of it self,) nothing of spring or Elasticity (otherwise then by reason of some *Airy* parts, or other elastick bodys, which may be included within it,) is generally held; at least none considerable, such as by any experiments hitherto made, can be clearly evinced so to be.

But, that the *Air* (such *Air* at least as is the common *Air* which we are conversant with,) is Elastick; is, I think, out of doubt: the experiments which prove

its spring, being so many and evident, beyond exception.

And, that this spring of the *Air*, is some times stronger, and sometimes weaker, I think is undoubted also. And, that the spring of the *Air*, is strengthened both by compression, and by heat, but in a different manner.

If the same quantity of *Air* be compressed into a lesser room, the spring is certainly stronger. As is undoubtedly seen in the Wind-Gun, and other compressive Engines. And from hence it is, that *Air*, of the common texture with the external or open *Air*, if it be (retaining its own texture,) included in a close Vessel (as in the *Air-Pump*,) whereby it is excluded from communication with the external *Air*, and defended from the pressure of it, doth yet sustain *Quick-Silver* in a Tube (after the *Torricellian* manner,) at as great an height, as the open *Air* by its counterpois would have done. Which cannot be by its weight (which, in this cause, is but small; and not equal to that of a cylinder thereof contained to the height of the *Atmosphere*;) but by its spring only; which is now pressed to as great a degree as it was in the open *Air* (by such weight as was then incumbent on it,) or would be now, if so again exposed. (Like as that of a Fleece of *Wooll* would be, if confined to the same dimensions it had, when a great pile of Fleeces was incumbent on it.) But if some of this *Air* so included (in the *Air-Pump* or such other close Vessels,) be Pumped out, whereby the residue thereof hath a greater room to possess than before it had, (namely, as much as before the whole of it did possess,) the *Quick-Silver* will presently subside, because the spring of the *Air* which did before sustain it, is now (by expansion,) become weaker.

Again; the same quantity of included *Air* in a close Vessel (so as not to communicate with the external *Air*,) will, by application of heat to it, have its spring strengthened, and drive its counterpois farther off, or (if need
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be,) compress it. As is to be seen in Thermoscopes of all sorts.

Whether, by strengthening the *Air's* spring (in that discourse,) he means that of the former or the latter way, I do not well remember. Nor, whether he apply it to the increasing, or diminishing, of its intensive weight. But it may be reasonably accommodated either way.

If the spring be strengthened by compression; it is manifest that the intensive gravity must be thereby increased: because the same quantity of *Air*, and consequently of weight, extensively taken, is now contracted into a lesser room, which therefore must be intensively heavier, (as being the same weight in a lesser bulk:) Now this may possibly, as a greater pressure or stronger spring, force up the Vapours under it with a greater *impetus* (according to the notion I mentioned before,) and so make them fly higher: (unless we should suppose, it may be relieved, by shortening the height of the *Atmosphere*;) but not so as to make them lighter; but rather the contrary, as pressing them closer: much less to make them (as the phrase is,) *specifically* lighter than is the *Air* it self (though thus compressed,) and it leaves less room to receive them between the particles of the compressed *Air*, as being now thrust closer together.

If the spring be strengthened the other way; so as by heat it useth to be: this doth rather diminish its intensive gravity, by thrusting its parts further asunder, and so possessing a larger room. Now in case this *Air* be, by a close Vessel, confined so as not to expand upward; it will certainly press the harder on the stagnant *Quick-Silver* under, and make that in the Tube rise higher. But in case it be unconfined, as in the open *Air*, it may as well relieve it self upward, by making the *Atmosphere*, in this part so much higher.

Nor is there any necessity, as to the subjacent parts,

that the *Atmosphere* should be every where of the same height. But the laws of Staticks, as to the subjacent parts, be equally preserved without it, (the greater altitude compensating for the levity of the parts,) as when a Portion of the *Sea*, is covered with a Fleet of *Ships*; the under parts are equally pressed, partly by water, and partly by *Ships*, though the tops of the *Ships* over some parts be higher then the surface of the water over others. One-ly, in such case, the upper part of the *Atmosphere*, being fluid, may flow collaterally over the other parts on either side if lower. And so, at leisure, (if thus remaining, otherwise undisturbed,) reduce it self to an equal height in all parts. Like as the *Sea* would do, in a perfect calm, though otherwise its waves and billows are far from being in all places perfectly plain and even.

But however, though the spring fortified by heat, may thus relieve itself upward, (yet because it presseth every way,) it must endeavour the like downward also, and thereby press harder on what is under it; and because it will require time to work upward gradually before the effect reach the top of the *Atmosphere*; and because, by such dilatation of its parts, more room is left in the intervals to receive what is forced: 'tis reasonable to believe, that, in such cases, the pressed vapours (*ceteris paribus*,) may rise more copiously then when the spring of the *Air* (for want of heat,) is less strong. The rather because the same heat which thus fortifies the spring of the *Air*, doth also rarify the Vapours and make them lighter: and may also fortify the subterranean heat (or what ever else it is,) that drives them up. Notwithstanding all which, we have more rains in winter; which should argue, that more Vapours do then arise to supply them.

But I suspect that, in this whole business (of strengthening the spring,) there may be a fallacy put upon us. And
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what we think to be done upon the open *Air* ; is indeed done upon the *Quick-Silver* ; or rather upon the *Air* latent therein.

My meaning is this. We find that in very hot weather, and also in frosty weather, the *Quick-Silver* in the tube commonly stands very high ; from whence we are apt to conclude, that therefore the outward *Air* presses very hard on the stagnant *Quick-Silver*, without the tube. Wherein I am not satisfied.

For we are to consider, that, in filling the Tube with *Quick-Silver* before it be inverted, if great care be not used to cleanse it from *Air*, many aery particles will remain mixed with it ; which, while their spring is weak, are easily pressed by the weight of the *Quick-Silver* close as hardly to be discerned otherwise then by the effect ; but when, by the external heat, their spring is strengthened, they expand themselves, and cause the *Quick-Silver*, wherein they are, to swell in bulk, without increasing its weight ; and consequently to stand higher though not to press heavier.

Of this I had manifest experience, when (many years since) I did for five or six years together constantly observe the height of the *Quick-Silver* in the tube, and kept a register of it, and of the weather with it: and did for two or three of the first years observe, that in very hot weather the *Quick-Silver* commonly stood very high. But, for some of the latter years, I found it much lower in hot weather then in those former years. Of which I satisfied myself with this account ; that, in those former years, the Tube having been but lately filled, the aery parts remaining in the *Quick-Silver*, being by the heat expanded, made the *Quick-Silver* to swell and stand higher: but, when the *Quick-Silver*, by divers years standing unmolested, had by its own weight cleansed it self, and forced that *Air* (which had been in it into the upper part of the glass ; it now ceased to make the *Quick-Silver* swell higher,

higher, but rather (by expanding it self in the upper part of the glass,) pressed the *Quick-Silver* downward. And I suspect, that others (without heeding it,) may have been in like manner imposed upon, as I was; especially while their *Baroscope* hath been but newly prepared, and not well cleansed of *Air*.

And the same account, perhaps, may serve for its standing so high in frosty weather. Water, we know, though it contract with cold, yet when it comes to Frieze doth expand it self. (Which makes Ice lighter then water, and to swim on the top of it.) Now whether this be purely of it self, or (in part at least,) from the particles of *Air* lodged in it, may not perhaps be so easy to determine. However, if there be the like effects on *Air*, as on water, (namely, that it expands with Friezing;) or if, in the *Quick-Silver* there be lodged particles of water as well as of *Air*; we have, either way, an account of this Phænomenon. For, then, the small particles, whether of *Air*, or water, lodged in the *Quick-Silver*, being thus expanded by friezing, will make the *Quick-Silver* swell, and so stand higher, without increasing its weight; and consequently, without arguing a greater weight of external *Air* pressing on the stagnant *Quick-Silver*.
